REPAIRS TO RISERS IN THE SHAFTS OF THE CITY TUNNEL OF THE CATSKILL AQUEDUCT[1]

By J. Waldo Smith

The most obvious means of delivering 500,000,000 gallons daily of Catskill water to the five boroughs of Greater New York was through pipe lines laid just below the street surface. In order to avoid the many difficulties which such a plan would have involved, by reason of interference with traffic and with subsurface structures, and also by reason of the high expense, it was determined to do as much underground work as possible. This decision resulted in the construction of a tunnel 18 miles long, circular in cross-section and with an inside diameter varying from 15 feet at the northern end of the city to 11 feet in Brooklyn. From the terminal shafts in Brooklyn, pipe lines were constructed to the boroughs of Queens and Richmond, the latter on Staten Island.

The construction of tunnels for carrying water under pressure was not new. In order to determine the best location beneath the congested area of the city and through the complicated geological formations which the tunnel in its natural location would penetrate, much exploratory work in the way of borings was necessary. These borings disclosed the character of the rock, and from the results thus obtained it was determined that the tunnel should be located at such depth that nowhere would there be less than 150 feet of rock cover. In general the rock cover is materially greater than 150 feet.

The tunnel is connected with the distribution system through 22 shafts, in each of which there are one or two steel riser pipes 48 or 72 inches in diameter. These pipes are controlled just below the surface of the ground by a substantial valve equipment. The riser pipes placed in the shafts are surrounded with concrete for their entire length, and are thus in a sense integral with the rock through

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which the shafts and tunnel were driven. The tops of these riser pipes are in the form of tees of solid bronze, and to these tees are bolted 30-inch and 48-inch solid bronze gate valves. The construction at the tops of the riser pipes was the very best and most substantial of which it was possible to conceive, and while it was believed that these bronze gate valves were sufficiently secure to control the supply it was nevertheless thought best to provide one other line of defense by locating a valve from 150 to 200 feet below the surface of the ground and directly attached to the end of the steel riser pipe. These valves, constructed of solid bronze throughout, were of special design and became known as riser valves. They were of two sizes, 48 and 72 inches in diameter, and are operated through a dashpot which has an area equal to one-half that of the waterway in which the valve is placed. The principle of operation is such that if the pressure within this dashpot is at any time reduced below that existing within the riser the valve will immediately and automatically begin to close.

This principle of valve operation has been turned to account by introducing a mechanism which will automatically control the valve operation in case a large break in the distribution system should occur and a dangerous flow of water through the riser pipe result. The operating mechanism for each of these valves is located in the underground chamber at the head of the shaft, and consists of a pair of pitot tubes, one of which looks upstream and the other looks downstream within the shaft riser. The pressures indicated by these tubes are led to two mercury chambers, in one of which there is a large cast-iron float connected through gears to a dial and tripping mechanism. As the pressures indicated by the pitot tubes vary, the position of the float varies and the position of the pointer with respect to the tripping mechanism also varies. As the velocity of flow through the riser pipes increases, the difference in pressure between the two pitot tubes increases, the difference in level between the two mercury chambers increases and the cast-iron float moves, so that finally, when the motion has become great enough, the tripping point of the mechanism is reached. A weight then drops and opens a small automatic valve, and thus immediately the pressure within the dashpot of the riser valve is lowered and the valve itself begins to close. The control mechanism is so designed that the tripping point may be set to accommodate a range of velocities within the riser pipe of from 2 to 15 feet per second.

Control of the rate of closing of the riser valve is had by passing the water discharged from the dashpot, as the valve closes, through a cylinder, from which it escapes through a number of openings or ports. The number of these ports which are open at any time is dependent on the position of the riser valve with respect to its seat. At the beginning of closing, all the ports are open and the valve approaches its seat until only one port or small hole $\frac{1}{32}$ inch in diameter remains open. In this way the speed of closing is held under strict control and the danger of water hammer is eliminated. The entire apparatus is so arranged that the riser valve will close from wide-open to tight-shut in approximately eleven minutes.

Extending from the riser valves to the surface are the riser pipes, which were constructed of sections of riveted steel pipe, the lengths of which varied from 15 to 30 feet. The original design prepared by Designing Engineer Wiggin called for a bolted transverse joint between the sections of steel pipe and recent experience has demonstrated that this should have been used. During construction, however, great difficulty was found in carrying out this plan and a type of hub-and-spigot joint was substituted. This joint was made by riveting an angle-iron seat around the outside of an upstanding end of each section of pipe; the next section of pipe was slightly tapered so that its bottom end was sufficiently large to slip over the upstanding end of the lower section. The upper section then rested on the angle-iron seat and formed an annular space between the ends of the pipe sections. This annular space, about $\frac{1}{2}$ inch in width by 3 inches in depth, was then calked with lead wool. The abutting ends of the steel pipes were reinforced with steel bands, so as to withstand deformation resulting from the calking with lead wool.

As the shafts were sunk, they were first lined with a thin wall of concrete, so as to avoid the necessity of timbering and in order to cut off water which would otherwise have entered from the rock through which the shaft passed. After the tunnel had been completed, the riser valves were built in, and above them the steel riser pipes placed in position, with joints between sections as previously described. The entire space between the concrete of the shaft lining and the riser pipes was then solidly filled with concrete. This concrete surrounding the pipes was usually brought to within about 1 foot below the joint in the riser pipes. After the erection of the steel riser pipes was completed, they were lined inside with 4 inches of concrete as protection against corrosion. It was recog-

nized that, due to the shrinkage of the concrete, slight leakage might occur, and to overcome this grout pipes were placed during the process of placing the concrete and these pipes were subsequently thoroughly grouted. It was also believed that the lead calking would take care of any slight vertical movement which might occur in the riser pipes.

In December, 1917, about at the beginning of cold weather and after the tunnel had been in operation for about a year, it was noticed that there was an inflow of water into the subway at 42d Street. Shortly thereafter water made its appearance in Bryant Park, near the corner of Sixth Avenue and 42d Street. At first it was thought that a break in one of the distribution mains had occurred and the valves at the head of the riser pipes were closed. This did not check the flow, and thereupon the riser valves were shut and the flow stopped. It was thus evident that a break had occurred in the riser pipe somewhere between the riser valves and the valves at the top of the riser pipe.

Preliminary study led to the conclusion that one of the joints in the riser pipes had failed, probably by reason of lifting action by the building up of hydrostatic pressure on the area of some one of the concrete construction joints, and that this pressure had been sufficiently great to result in a lifting force of sufficient magnitude to raise the weight of the superimposed shaft concrete, together with that of the valve chamber and its earth covering, including, of course, the weight of all the valves and fittings within the chamber. The action was analogous to that of a hydraulic ram. A small quantity of leakage water evidently passed through one of the joints in the steel riser pipe and found access to the construction joint in the concrete in its immediate vicinity. This pressure was thereupon spread over a great part of the area of the construction joint, which was substantially equivalent to that of a circle 14 feet in diameter.

With the riser valves closed, the riser pipes were pumped out and examined. This examination confirmed the conclusion which had been reached on consideration of all the conditions as above explained, and it was found that there had been a vertical movement of about $\frac{3}{4}$ inch and that this movement had extended across the entire shaft and had broken joints in both of the riser pipes at a distance of 58 feet below the bottom of the valve chamber.

For the purpose of operating the riser valves there are in this shaft two 3-inch and two $1\frac{1}{2}$-inch bronze pipes. These pipes extend

vertically from the chamber to the riser valves and passed directly across the plane of rupture. It was indeed surprising to find that these pipes had succeeded in withstanding this amount of deformation without rupture. It was evident that they had not broken when it was found possible to close the riser valves immediately after the break had occurred. Later on, when they were exposed to view, it was found that two of them were still intact, although the other two had broken at the threads in each case close to a coupling. The breakage here was probably due to fatigue and did not occur until sometime after the valves had been closed.

The repairs made consisted in placing bronze sleeves about the bronze pipes, removing the lead calking between sections of steel riser pipe and welding these steel riser pipes together by means of the electric arc. In order to gain access to the bronze pipes, which were located outside the risers, it was necessary to cut out of the steel risers pieces large enough so that the removal of the concrete around the pipes could be accomplished. These pieces cut from the riser pipes were also subsequently replaced by welding with the electric arc.

It is believed that the work done has resulted in assuring a greater degree of safety than that called for by the original designs, and that the shaft now is more secure than it was at any time previous. It is even now difficult to conceive just how the break could have occurred, because the concrete with which the shaft was originally lined would hardly have had the strength necessary to withstand the pressure which must have accumulated before the break occurred, but no other reasonable explanation has been advanced.

It was natural that this occurrence at one of the shafts should have directed attention to all of the other shafts where conditions were generally similar. Careful detailed study of these cases was thereupon undertaken, and it was determined to do everything which could be done toward eliminating similar conditions, to the end that the greatest possible degree of security at all of the shafts should be obtained. Pursuant to this policy two things were done. First, a series of borings were put down through the concrete so as to intersect the construction joints in the concrete around the riser pipes. These borings act as vents and will operate to prevent the building up of hydrostatic pressure on the area of any one of these joints. Second, a sufficient number of joints in each shaft were welded in the same manner that the repair at Shaft 17 was made,

so as to afford a very material increase in vertical strength, thus resulting in a balancing between any vertical hydrostatic pressures which might occur and the weight available to resist such hydrostatic pressure.

Tests of samples of the welding, when pulled in the testing machine, have developed over 80 per cent of the vertical strength of the section, and have thus shown a greater strength than that which could have been reasonably attained by any form of welded joint.

It was indeed fortunate that Catskill water became available when it did. The first general delivery was made in January, 1917, at which time Brooklyn was already in bad straits. Last winter, during the extremely cold spell, had it not been for Catskill water, New York City would have been as badly off as Jersey City was, but this is something which the average citizen does not realize, and a condition such as there existed is fully understood only by a water-works man.

DISCUSSION

W. W. Brush: At about 9 p.m. December 11, 1917, the Department of Water Supply of New York received word of a serious water leak that had developed in the subway tunnel at 42d Street. The repair gangs and emergency engineer were called out, and first tested the distribution mains at this location. There are several lines of water mains in and crossing 6th Avenue at 42d Street, and all had to be successively shut down to determine whether any were leaking. At about 2 a.m. it was evident that the leak was on the Catskill system, either from the Catskill shaft or from the tunnel. During the time the source of the leak was being investigated the leakage had increased in volume and amounted to probably some 10,000,000 gallons daily. The water had raised the floor of the subway sufficiently to make it questionable whether the subway trains could continue to operate, a heavy stream was flowing down the subway floor, and water in large volume was coming up along the curb and sidewalk on 6th Avenue, and also within the limits of Bryant Park.

At 2.30 a.m. orders were telephoned to start up the pumping stations on Long Island, where some thirty-two stations that formerly supplied the municipal service in the boroughs of Brooklyn and Queens had been shut down, and placed in reserve. At the same time an order was given to close the emergency riser valves

that were placed in the shaft 100 feet or so below the surface of the rock. It was not then considered likely that the leak was from the shaft, but this was considered a possibility. The department was greatly relieved to get word at 3 a.m. that shutting down the riser valves had stopped the flow, and that it would not be necessary to shut down the main Catskill tunnel. Had it been found necessary to shut down the tunnel, it would have meant cutting off the entire water supply for the boroughs of Brooklyn, Queens and Richmond, and from the lower part of Manhattan. There are two main line valves in the 17½ miles of Catskill tunnel between Hill View reservoir and Brooklyn, one at about 93d Street and Central Park, and the other at 24th Street and 5th Avenue. Both of these must have been closed had the main tunnel ruptured at Bryant Park. To provide against an interruption in the supply of water to Brooklyn and Queens, the department maintains ready for operation nineteen pumping stations connected with the Brooklyn system, and two connected with the Queens system, these stations having a combined capacity of about 150,000,000 gallons daily. In Richmond only two stations are so maintained, having a total capacity of about 8,000,000 gallons daily, as in Richmond there is sufficient stored water in the Silver Lake reservoir to maintain the present demands for a period of about twenty-five days. In Brooklyn and Queens the water stored in the distribution reservoirs would only meet the present demands for a period of less than two days. Some of the city officials have questioned whether the department is warranted in keeping these Brooklyn, Queens and Richmond stations in reserve, ready to operate, and the Board of Estimate and Apportionment that went out of office on December 31, 1917, reduced the number to be maintained in Brooklyn from nineteen to six. This action was reversed by the present Board of Estimate and Apportionment. The cost of maintaining the stations is somewhat less than $200,000 a year. The speaker is certain that no one who had had the experience that he passed through at the time the leak developed at 41st Street and 6th Avenue would question for a moment the advisability of spending this money for insurance, and maintaining the pumping stations connected with the Brooklyn, Queens and Richmond systems ready to operate upon demand.

A few words as to the necessity of the Catskill system to maintain the water supply of New York may be of interest. The unusual severity of the winter of 1917–1918 placed upon virtually all the

water supply systems in the northern part of the country a most unusual burden, due to the very large volume of water drawn to prevent the freezing of pipes and fixtures. In the borough of Brooklyn the consumption on one day reached a maximum of 230,000,000 gallons daily as against a previous average consumption of about 140,000,000 gallons daily. This very high consumption continued for a sufficient period, so that had it not been for the Catskill system, the consumption in the borough must have been reduced by some 30,000,000 gallons daily, with resultant distress and fire danger to property, caused by the general lowering of pressures. In the boroughs of Manhattan and the Bronx, the situation did not indicate quite so clearly the absolute necessity of the Catskill supply, but here the consumption in the months of January and February averaged 425,000,000 gallons daily, whereas the safe supply from the Croton, Bronx and Byram systems is estimated at 350,000,000 gallons daily, these being the systems available prior to the introduction of the Catskill water. The Catskill system has efficiently met all the demands placed upon it, and New York is fortunate in having had at its command during last winter this great source of water supply.